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BULLETIN NO. 20.

U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF ROAD INQUIRY.

TRACTION TESTS.

BY

SAMUEL T. NEELY,

Assistant Engineer, Office of Road Inquiry.

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1896.

United States Road Exhibit, Cotton States and International Exposition, Atlanta, Georgia, 1895.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Road Inquiry,
Washington, D. C., July 2, 1896.

Sir: I have the honor to transmit and recommend for publication as Bulletin No. 20 of this office a paper prepared by Mr. Samuel T. Neely, assistant engineer, upon traction tests on public roads.

Very respectfully,

Roy Stone,
Special Agent and Engineer.

Hon. J. Sterling Morton,
Secretary of Agriculture.

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TRACTION TESTS.

In considering the cost of moving freight over common roads this statement may be taken as true: The ultimate cost of moving freight is in proportion to the force required to draw a given load. If, in other words, it requires twice as much force to draw a load of 1 ton over one kind of road as over another, it will cost twice as much to move freight over the former road as over the latter.

PREVIOUS TRACTION TESTS.

In order, then, to compare the costs of hauling on different kinds of roads it is necessary to determine the amount of force required to draw a given load over each of the roads in question.

With this object in view experiments were made at various times during the first half of the present century. The two men whose results seem to be the most reliable and are the oftenest quoted are M. Morin, who made experiments for the French Government, and Sir John McNeill, who experimented in England.

The results obtained by the latter were published by Sir Henry Parnell in 1838. They are given in the form of a table which shows the number of pounds required to draw 1 ton over the several kinds of roads then and now in common use.

The data furnished by M. Morin's experiments were published in 1843. The tractive force is given in fractions of the total load drawn. His table is very comprehensive and considers not only the kind of road, but also the style of vehicle and the rate of speed. From this table he draws certain general conclusions as to the effect of speed, etc., on the tractive force. The tables and remarks are given in full in the appendix to this bulletin.

Since that period these results have been taken as authority. They have furnished the bases of all calculations made to determine the economic value of different kinds of roads. However, conditions necessarily change in the course of fifty years. There are still macadam roads and telford roads and dirt roads and sand roads, but a macadam road of to-day in the United States is different from a macadam road of 1843 in France or of 1838 in England. Asphalt has come into common use for city pavements. The construction of vehicles has improved. It seems desirable, therefore, that new experiments be made in order to determine the value of tractive force in the case of vehicles and roads now in use.

With such an end in view this Department has just completed a series of experiments on traction. The first experiments were made on the roads of the United States road exhibit at the Cotton States and International Exposition in Atlanta, in 1895.

This exhibit consisted of three specimen roads—a modern macadam road, a sand road, and an ordinary dirt road. The macadam road was 300 feet in length, made up of six 50-foot stretches, each of a different grade, the first being level, the others rising 2 feet in 100 feet, 4 feet in 100 feet, 6 feet in 100 feet, 8 feet in 100 feet, and 10 feet in 100 feet, respectively. Each of the other roads was 200 feet in length, divided also into 50-foot stretches, the first being level, the others rising 2 feet

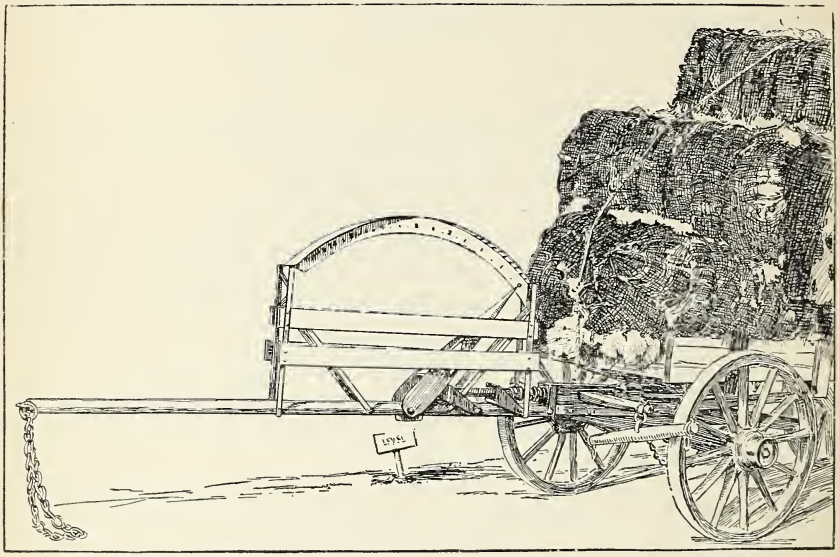


FIG. 1.—Tractometer attached for use.

in 100 feet, 4 feet in 100 feet, and 6 feet in 100 feet, respectively. The macadam road was covered to a width of 12 feet with blue Trenton limestone brought from the quarries near Chattanooga, Tenn. The macadam pavement was 6 inches thick, being made of 4 inches of stone so broken that the greatest length of any stone was 2 inches, over which a 2-inch layer of screenings was placed. The subgrade was made of the natural clay, well rolled, so as to conform to the finished surface of the road. All the rolling was done with a 15-ton steam roller. After the bed was finished the 4-inch layer of 2-inch broken stone was put in place and was also rolled thoroughly. Finally, the 2-inch layer of screenings was placed upon this, sprinkled until thoroughly wet, and then rolled till the surface was perfectly smooth.

The sand road was made by putting 6 inches of river sand on a bed of natural clay. It also was 12 feet in width. Neither the bed nor the

surface was rolled. It was the aim to make the road as nearly similar to the ordinary Georgia sand road as possible.

The dirt road was made by grading up the natural earth found on the terrace. This was made thoroughly wet and a narrow-tired wagon heavily loaded was drawn back and forth over it until deep ruts were formed. This resembled very closely the average mud road as it is found throughout the country during the greater part of the year.

After these roads were completed the traction experiments were made upon them in the following manner: A heavy farm wagon loaded with cotton bales was drawn first over the macadam road and then in succession over the sand and dirt roads. The amount of pull exerted at any time by the team was indicated by means of a tractometer designed especially for these tests, a cut of which is given below.

TRACTOMETER TESTS.

The amount of force which the team exerted was weighed by the spring *S*, in compression, and was indicated on the arc *A* by means of the pointer *P*. The smaller spring sufficed for all forces below 600

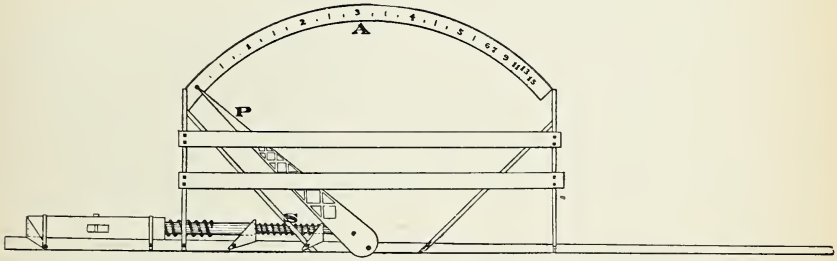


FIG. 2.—Tractometer.

pounds. After this mark was reached the larger spring came into play. The arc showed above the backs of the team, and as it was marked with large figures it could be easily read from the roadside. No precaution was taken to check or lessen the oscillations of the index arm beyond that of making the parts entirely snug. This insured the fact that there was no lost motion in the machine, and therefore the oscillations were caused directly by the variation in the amount of pull. Although the to-and-from motion of the index made it impossible to read the scale accurately, it indicated the true state of affairs, which was as follows:

On the smoothest possible macadam road surface the force of traction was not constant, but changed continuously within a range of 50 pounds.

On the ordinary dirt road the force varied from absolute zero to 700 pounds (in a gross load of 3,000 pounds), becoming in effect a rapid succession of violent jerks.

On heavy grades, in the case of the smooth road, the force was more nearly constant.

The force necessary to start a load on the smooth road was four times as great as the force required to draw the load at a uniformly slow pace when started and was one-tenth the gross load.

The force required to start a load on the dirt road was about one-fourth the gross load, or not greatly in excess of the upper limit of the tractive force when the wagon was in motion.

From these observations the following conclusions are drawn:

A team harnessed in the ordinary way is subjected to a continuous jerking motion, which on even the smoothest country road is enough to greatly increase the fatigue.

On a dirt road in bad condition this jerking motion becomes a succession of heavy blows transmitted to the animals by means of the collar. The fatiguing effect of these blows is probably double that of a steady pull equal to the maximum figure reached in the oscillations, and, furthermore, they bruise the shoulders of the team, thus lessening its value, besides being cruelly painful.

Starting a heavy load is also equivalent to a violent blow, as the driver ordinarily draws his team well back and then urges it suddenly forward against the collar held by rigid traces.

The smoother the road the more nearly constant will be the force of traction and the less will be the fatigue of the team while doing the same amount of work; that is, if a load four times as great can be drawn over a smooth road as over a rough one, by exerting the same amount of force, then a team can haul four times as much in the same time over the smooth road and suffer much less fatigue in the operation.

Some method should be adopted of making a more elastic connection between the wagon and the team, thus transmitting the shocks at the wheel rims as a gradual change of force to the team.

During these experiments a team of small mules readily drew 12 bales of cotton [1] on a heavy Studebaker wagon up the 10 per cent grade of the macadam road, the tractometer indicating a pull of 1,000 pounds. The same team was stalled completely in going down the 6 per cent grade of the sand road, after pulling the indicator to 1,900 pounds. Nine bales of cotton were removed before the load could be again gotten in motion. The driver refused to venture at all upon the dirt road with the twelve-bale load.

WIDE TIRES AND NARROW TIRES.

There was also a test made to demonstrate the practical advantages of wide tires over narrow tires. A piece of clay road was made thoroughly wet. Over one portion of the mud road thus formed a heavily loaded wagon with 2-inch tires was repeatedly drawn. Over the other portion a wide-tired wagon, whose gross load was made equivalent to that of the first, was hauled an equal number of times. The tires of the latter wagon were 4 and 5 inches wide and the front axle was

[1] A bale of cotton weighs about 500 pounds.

shorter than the rear, so that the wheels did not run in the same track. The result was very satisfactory. That part of the road which the narrow-tired wagon traversed was cut and rutted to the depth of several inches, while the remainder was rolled by the wide tires into a smooth surface. Afterwards the tractometer was brought upon this road and it was found that twice as much pull was necessary to draw the same load over that half of the road which had been subjected to narrow tires as over the other half.

CONCLUSIONS ON USE OF TRACTOMETER.

Each of these tests was repeated several times during the session of the National Road Parliament, which was held at Atlanta October 17, 18, and 19, 1895. In every case the results were highly satisfactory from a practical standpoint, and they demonstrated clearly to the onlooker the great advantages of a hard road. From time to time the amount of pull indicated by the tractometer was read as accurately as possible and recorded. On summing up the records it was found that about four times as much force was required to draw 1 ton over the level stretch of the mud road as over the level stretch of macadam.

However, as already stated, the oscillation of the pointer made it impossible to read the indicator with any degree of accuracy, and consequently the results obtained from the records, in terms of pounds of force required to draw 1 ton, are of little scientific value. In order to obtain results which would be accurate and of scientific value, it was necessary to so alter the tractometer that it would record the results automatically. In place of the arc and indicator, which were intended to show merely the amount of pull, it was necessary to put some apparatus which would make a graphic record of this amount. Several apparatus were suggested, besides those used by former experimenters, to accomplish the same end.

USE OF THE TRACTOGRAPH.

The one adopted seemed to be at once the simplest, cheapest, and most readily adapted to the rest of the machine. The apparatus was similar to that used on steam engines to obtain indicator diagrams. A cut of the machine as altered is here given in order to make it more easily understood. Since this machine records as well as measures the tractive force, it has been called a tractograph.

A long arm, holding a pencil at its end, was attached to the end of the piston which previously moved the pointer. The pencil point rested on a revolving cylinder which was placed in front of the spring and piston and extended longitudinally along the pole. This cylinder was made to turn by means of the gear shown in the cut, driven directly by one of the front wheels of the wagon. A further change was made by substituting a single long spring in place of the two short springs previously used.

It can be seen from the cut that any pull exerted at the doubletrees would compress the spring and cause the pencil to move forward along the cylinder; and, further, if a sheet of paper were placed around the cylinder the pencil would mark upon it the exact amount which the spring was compressed. Since the cylinder revolved as the wagon moved forward, a continuous record of the force exerted through any distance could thus be recorded. In order to read the amount of this force in pounds it was necessary to know the amount of compression in this spring which corresponds to a given pull. This information was obtained directly by placing weights upon a platform connected to the doubletrees by means of a rope and pulley. Weights differing from each other by 100 pounds and ranging from zero to 1,200 pounds were used. The point to which each successively brought the pencil

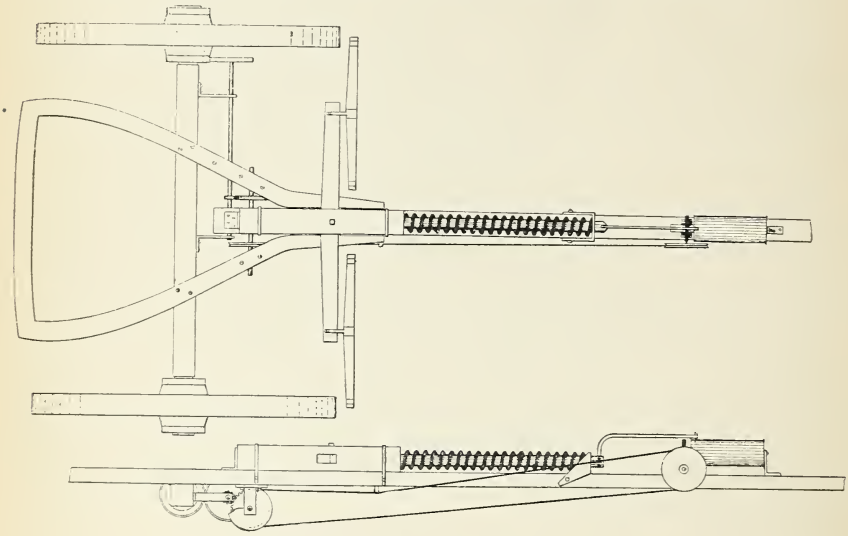


FIG. 3.—Tractograph.

was noted on a blank sheet. The spring was found to obey the law of compression—i. e., the amount of compression was proportional to the weight applied, and each 100 pounds caused the compression of three-quarters of an inch.

From the data thus obtained sheets were ruled into spaces, each corresponding to a pull of 10 pounds. It is also found by experiment that the cylinder revolved once while the wagon moved forward 1,316 feet. From this information the sheets were ruled transversely into spaces, each of which corresponded to a distance of 100 feet. With this it was possible to get not only a continuous record of the force exerted through a given distance, but also the exact amount of pull employed at any point of the road.

Four diagrams are published herewith, which show the results obtained, respectively, on a level asphalt street, on a level macadam

road, on a level dirt road, and on a macadam road ascending a hill of 10 per cent grade.

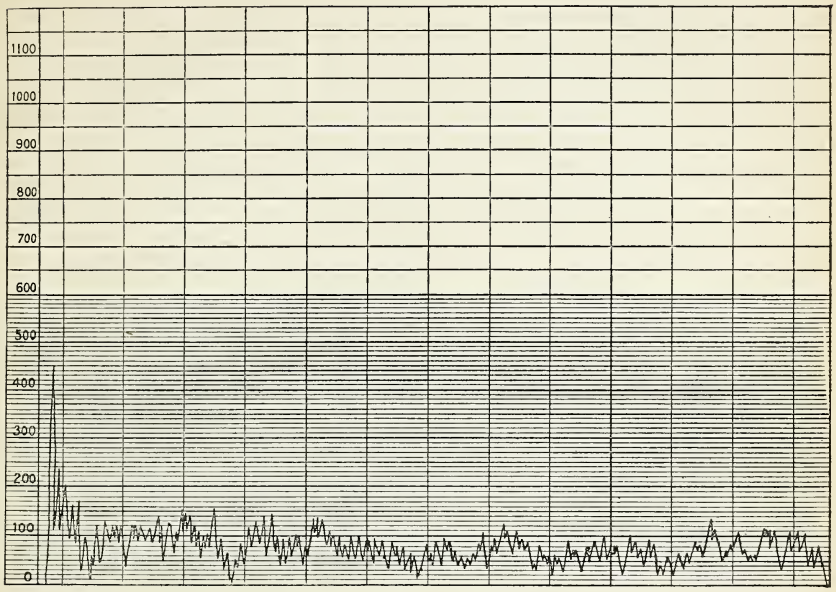


FIG. 4.—Diagram showing record of tractograph on a smooth asphalt street.

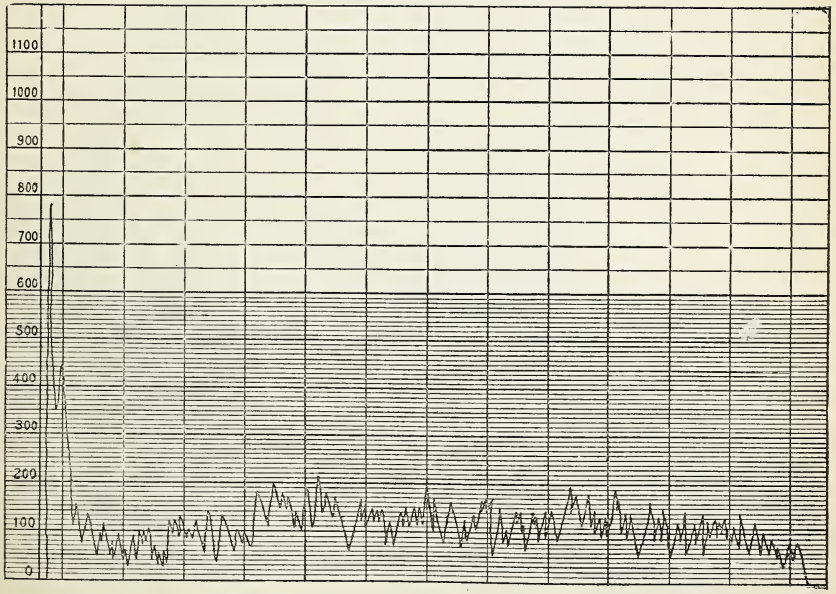


FIG. 5.—Diagram showing record of tractograph on a smooth macadam road in good condition.

The asphalt street was not in good condition, being full of patches, and on that account the pull was more uneven than it would have been on a perfect surface.

The macadam road tested was in excellent condition and as nearly level as it is practicable to make an actual road. As it is a public road

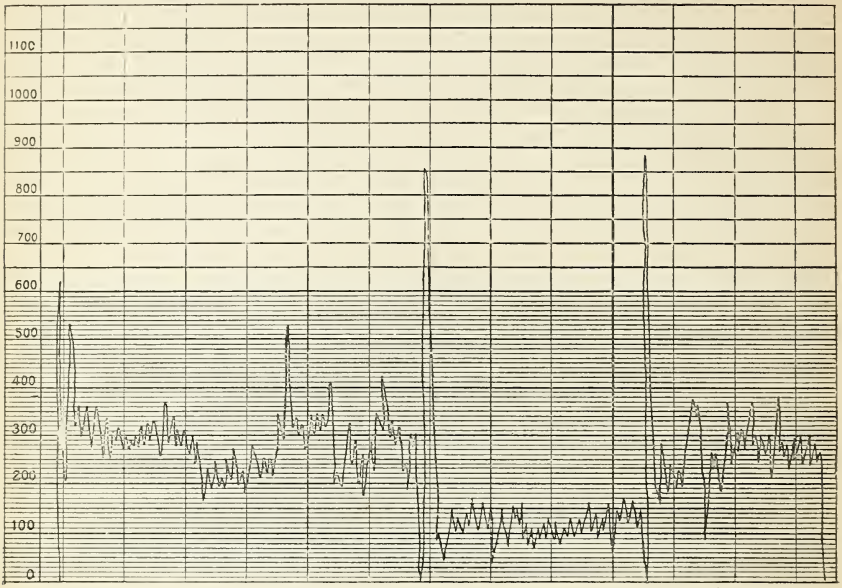


FIG. 6.—Diagram showing record of tractograph on a smooth dirt road.

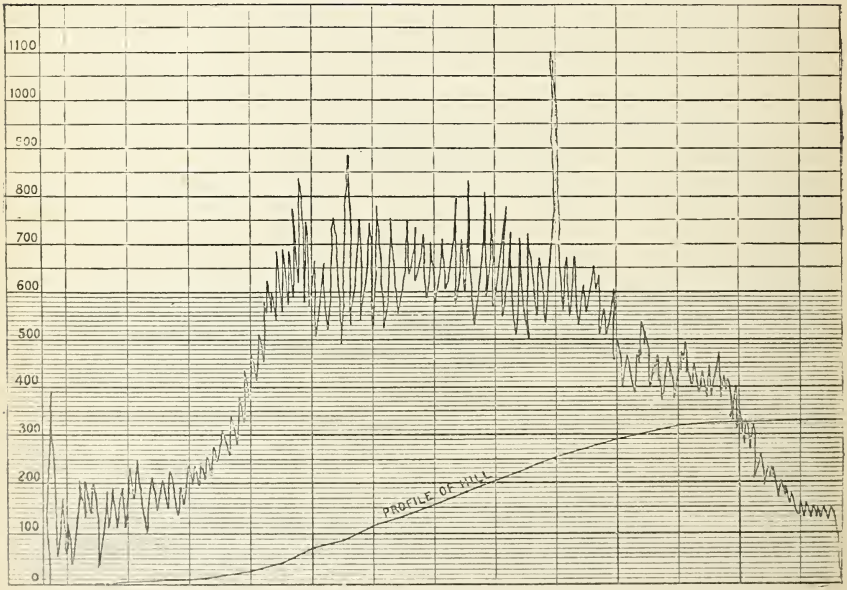
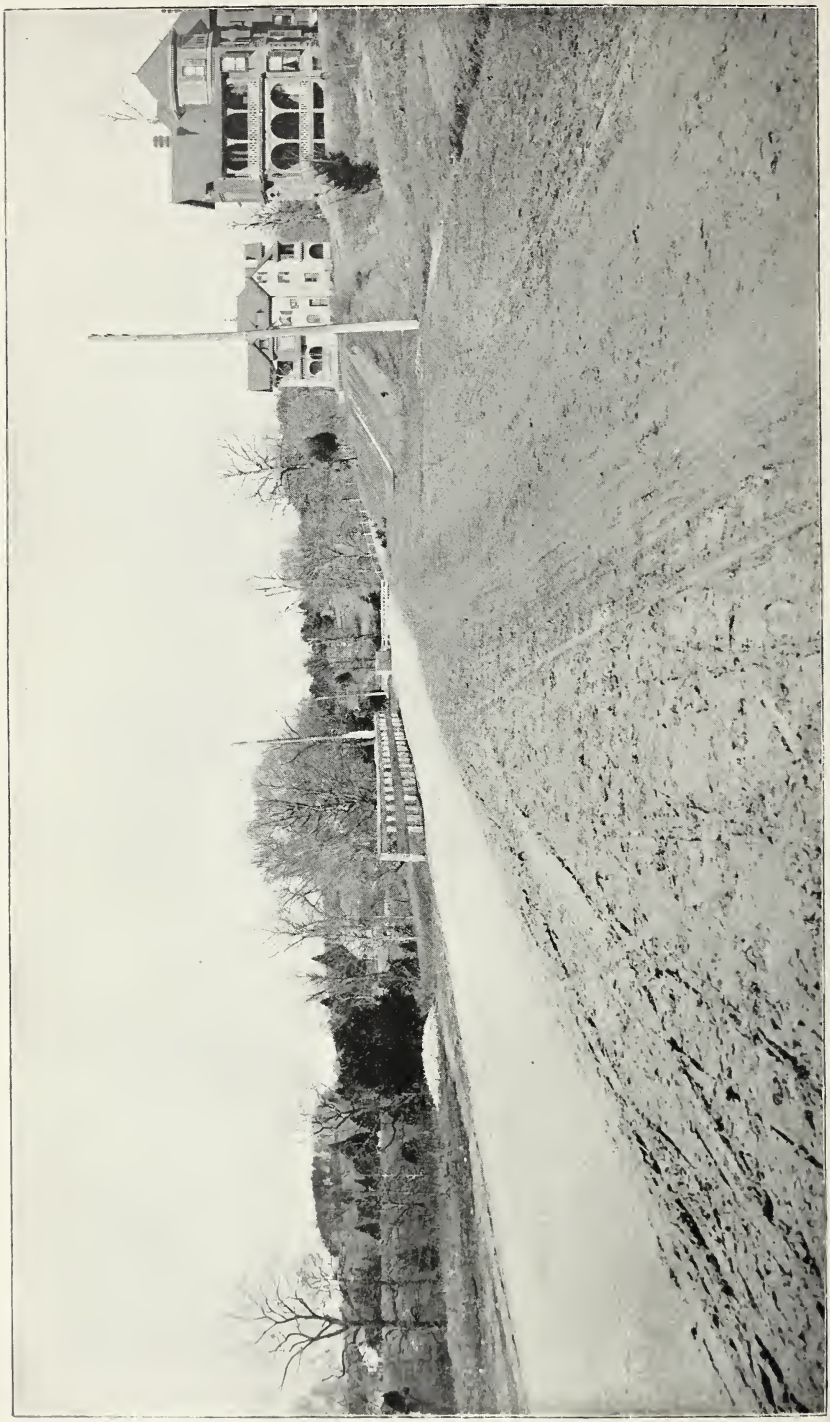


FIG. 7.—Diagram showing record of tractograph on a macadam road ascending a hill of 10 per cent grade.

in constant use (being in fact a portion of the famous Conduit road, which runs west of Washington, D. C., see Pl. II), the conditions met



VIEW OF CONDUIT ROAD WEST OF WASHINGTON, D. C.

with and the results obtained are such as we may hope to secure in any country highway.

The dirt road, also, was in the best condition possible, being dry, firm, and smooth. It lay alongside the macadam pavement on this same Conduit road, and it was noticed that drivers with light teams used it in preference to the macadam. In making this test it was necessary to cross the macadam pavement. The records show very plainly where the crossing occurred, as the team was stopped momentarily on either side of the hard pavement. It also shows, without going into the figures, that the draft on a dirt road is about two and one-half times as much as that on a macadam road, and this when conditions are most favorable to the former, namely, when it it perfectly dry and smooth.

The fourth diagram (fig. 7) is given to show the effect of a very steep hill. It required constant urging to keep the team in motion at all in ascending this grade, and to their unsteady gait is due to a great extent the zigzag appearance of the record. However, it serves to show that it required nearly seven times as much effort to draw the load up the 10 per cent grade as along the level roadway. Furthermore, allowing that a team can exert, without harm, for a distance of some 500 feet, twice as much effort as it could sustain for a great distance, it is evident that the presence of such a hill limits every load drawn over the road to one-third of what might be drawn if it were not there.

It may be well to call attention to the amount of force which is required to start a load under any condition, as shown by the beginning of each traction curve. It seems to require anywhere from four to eight times as much force to start a wagon as to keep it in motion afterwards.

Such is the method of measuring and recording the force of traction by means of the tractograph. It still remains to obtain from the record a number which will be the average amount of pull on the road tested, and from this to get the pull per ton so that a comparison with results obtained on other roads and by other experimenters may be made. Evidently the average pull desired is represented by the length of the average ordinate of the traction curve. The total area between the curve and the zero line is found by means of a planimeter. If this is divided by the length of the zero line included between the extremes of the curve the result will be the average ordinate required, which, as a consequence of the ruling of the sheet, will be the average pull in pounds. Of course this average when divided by the number of tons in the gross load will give the tractive force. (The tractive force will always be taken to signify the force required to draw 1 ton.)

Applying this process to diagram No. 1 (fig. 4), the force of traction is found to be 72 pounds, and since the gross load was 5,500 pounds, the force per ton (of 2,000 pounds) is 26 pounds on an asphalt pave-

ment in poor condition. From the record on diagram No. 2 (fig. 5) the tractive force on a good macadam road is found to be 28 pounds. In the case of the dirt road the force is found to be 96 pounds per ton, while on the hill of 10 per cent grade it is 236 pounds.

The results of experiments Nos. 1, 2, and 3 (figs. 4, 5, and 6), while each is gotten from a single sheet, are found to correspond very closely to the average of a large number of experiments, so that we may state that with a team going at an ordinary walking pace the tractive force on an old asphalt pavement is 26 pounds; the tractive force on a good macadam pavement is 38 pounds, and the tractive force on a good dirt road is 96 pounds.

The following results for the best macadam roadways are those gotten by former experimenters, and are taken from a table published by Mr. Rudolph Herring in the Engineering Record:

Authority.	Tractive force.
	Pounds.
Navier	45
McNeill	46
Rumford	50
Gordon	37½
Morin	32
Office of Road Inquiry	38
Average	41

For a dry, hard, earth road Morin gives from 75 to 102 pounds as the tractive force.

No attempt was made during the above experiments to determine the effect of different rates of speed or of different diameters of wheel. The rate of speed at which heavy loads are hauled is about the same everywhere, and the diameter of wheels on farm wagons seems to be that which is best suited to all the conditions.

The following general results are gotten from various experiments made by engineers already mentioned:

First, the force of traction varies universally as the diameter of a wheel.

Second, the force of traction increases with the speed, upon hard roads, but is not in proportion to velocity.

The width of tires is found to have no effect on the traction on hard roads, but it has a very decided effect on the condition of the road surface and on the cost of maintenance.

The effect of the inclination is a matter of mathematical computation entirely, and can always be figured from the following formula:

$$R = F + a\,W,$$

where F = Force required to draw the load on the level.

a = The grade expressed by a fraction.

W = The weight of the load in pounds.

R = Force required to draw the load up the incline in question.

In the case of the 10 per cent grade given above we have:

$F=102$ pounds for a macadam road.

$a=\frac{1}{10}$, grade in fraction.

$W=5{,}500$ pounds, total load.

$R=102+\frac{1}{10}\times 5{,}500=652$ pounds.

Whence the tractive force, $T=\frac{2000}{5000}\times 652=236$ pounds per ton, a result identical with that obtained by direct experiment, as given on page 18. Table No. 5, in the appendix, shows the amount of pull that will be required to draw 1 ton along a good macadam road of different grades, varying from a level to a rise of 1 foot in 10. It also shows the equivalent length of level road for 1 mile on each grade.

APPENDIX

EFFECTS OF SURFACE.

The following is Sir John McNeill's table:

TABLE No. 1.

Description of road.	Tractive force.
	Pounds.
On a well-made block pavement	33
On a telford or macadam	46
On an old flint road	65
On a road of loose gravel	147

The next table is part of that given by M. Morin. Instead of giving the traction in fractions of the total load, however, it has been calculated as pounds required to draw 1 ton to make it uniform with the other tables.

TABLE No. 2.

Kind of road.	Tractive force.			
	Carts, 3 miles per hour.	Wagons of 2 tons, 3 miles per hour.	Carriages with springs, 3 miles per hour.	Carriages with springs, 6 miles per hour.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
New road with 5 inches of gravel	166	222	250	.....
Earth road with one-half inch of gravel	125	191	200	.....
Broken stone in best condition	27	37	42	48
Broken stone very much rutted and very muddy	105	143	166	200
Pavement, clean	11	30	35	53
Pavement, muddy	14	40	45	66

Table No. 3 is taken from that of Rudolph Herring, which was published some years ago in the Engineering Record. The velocity in all cases is taken at 3 miles per hour.

TABLE No. 3.

Kind of road.	Tractive force.	Authority.
	Pounds.	
Loose sand	448	Bevan.
Loose gravel (deep)	320	Do.
Loose gravel (4 inches)	222	Morin.
Common gravel road	147	McNeill.
Good gravel	88	Rumford.
Hard rolled gravel	75	Minard.
Ordinary dirt road	224	Bevan.
Hard clay	112	Do.
Hard, dry, dirt road	89	Morin.
Macadam, little used	140 to 97	Do.

TABLE No. 3—Continued.

Kind of road.	Tractive force.	Authority.
	Pounds.	
Bad macadam	160	Gordon.
Poor macadam	112	Navier.
Common macadam	64	Peidounet.
Good macadam, wet	75 to 42	Morin.
Best French macadam	45	Navier.
Very hard and smooth macadam	46	McNeill.
Best macadam	50	Rumford.
Do	49 to 37½	Gordon.
Do	52 to 32	Morin.
Cobblestone, ordinary	140	Kossack.
Cobblestone, good	75	Do.
Belgian block	56	McNeill.
Belgian block in Paris	54 to 34	Navier.
Belgian block	37½	Rumford.
Belgian block, good	34½	McNeill.
Belgian block	50 to 26	Morin.
Stone block, ordinary	90	Minard.
Stone block, good	45	Rumford.
Stone block, London	36	Gordon.
Asphalt	17	Do.
Granite tramway	13½	Do.
Do	12½	Do.
Iron railway	11½	Do.
Do	8	Lecount.

Table No. 4 contains the results of traction tests made by the Office of Road Inquiry.

TABLE No. 4.

Kind of road.	Tractive force.
	Pounds.
Loose sand (experimental)	320
Best gravel (park road)	51
Best clay	98
Best macadam	38
Poor block pavement	42
Cobblestone	54
Poor asphalt	26

EFFECT OF INCLINATION.

Table No. 5 gives the tractive force necessary to draw 1 ton over the best macadam road of various grades and the equivalent length of each mile of grade in miles of level road.

TABLE No. 5.

Rate of inclination.	Angle with the level.	Tractive force.	Equivalent length of level road in miles.
	° ′ ″	*Pounds.*	
Level	0 00 00	38	1.00
1 in 500	0 6 53	42	1.10
1 in 100	0 34 23	58	1.52
1 in 80	0 42 58	63	1.66
1 in 60	0 57 18	71	1.87
1 in 50	1 08 16	78	2.05
1 in 40	1 25 57	88	2.30
1 in 30	1 54 37	104	2.73
1 in 25	2 17 26	118	3.10
1 in 20	2 51 21	138	3.63
1 in 15	3 48 51	171	4.50
1 in 10	5 42 58	238	6.26